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WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 5 :
H04B 7/185, G01S 5/02, H04L 27/30

A1

(11) International Publication Number: WO 94/15412

(43) International Publication Date: 7 July 1994 (07.07.94)

(21) International Application Number: PCT/US93/12179

(22) International Filing Date: 17 December 1993 (17.12.93)

(30) Priority Data:

07/992,892	17 December 1992 (17.12.92)	US
08/079,810	22 June 1993 (22.06.93)	US
08/115,087	2 September 1993 (02.09.93)	US

(60) Parent Applications or Grants
(63) Related by Continuation

US	07/992,892 (CIP)
Filed on	17 December 1992 (17.12.92)
US	08/079,810 (CIP)
Filed on	22 June 1993 (22.06.93)
US	08/115,087 (CIP)
Filed on	2 September 1993 (02.09.93)

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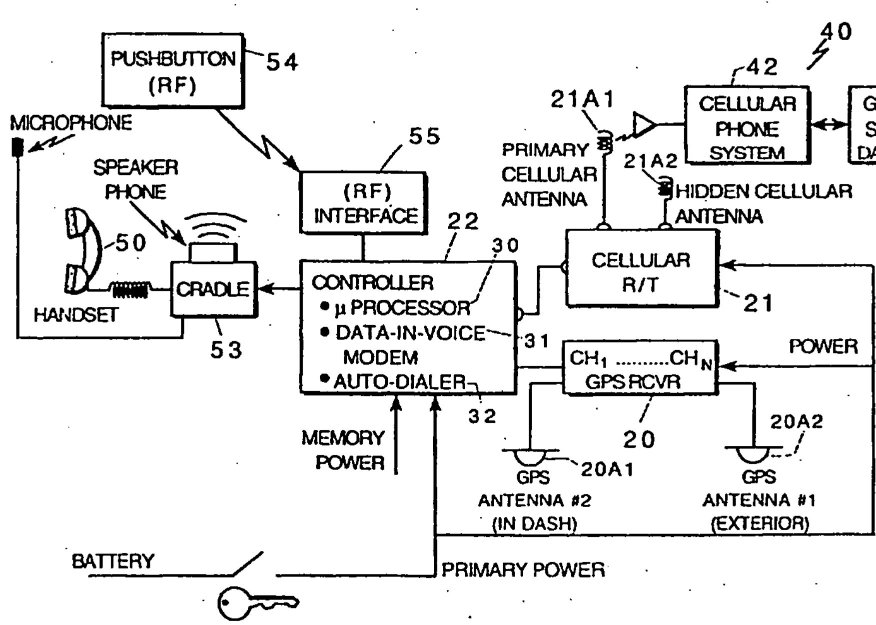
(81) Designated States: AU, BR, CA, JP, KR, US, European patent (AT, BE, CH, DE, DK, ES, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).

Published
With international search report.
Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.

(54) Title: HYBRID GPS/DATA AND MULTI-SERVICE LINK UNIT



(57) Abstract

A global positioning system (GPS) (20) in which a plurality earth orbiting satellites transmit position information to mobile radio stations on earth, is provided with a separate source satellite position data broadcast digital channels and one or more dial-up service separate communication channels (selected from a data link supported by terrestrial cellular telephone (42) and other radio packet data services (54)) for assisting the mobile radio station to access position information from the satellites. A controller (22) is coupled to the mobile radio station (55) for connecting to the separate communication channel for extricating the satellite position data via separate communication channel. The controller (22) includes a microprocessor (30) for processing the satellite position data to enable the mobile radio station to rapidly locate and access position information from said earth orbiting satellite.

HYBRID GPS/DATA AND MULTI-SERVICE LINK UNIT

This invention relates to method and apparatus for enabling rapid and accurate measurement of vehicle position, and more particularly to the global positioning system (GPS) for achieving precise position location in the urban canyon and other line of sight obstructed environments. It further relates to supplying the required data link over a cellular phone or other channel in order to support the measurement of GPS position, and to relay the resulting position measurements over the phone system to service providers that need to know vehicle position in order to provide services, such as:

1. A Emergency Roadside Assistance (ERA) service which will provide subscribers with the ability to request roadside services using their cellular phone without having to leave their car or know their exact location. Typical roadside services would include delivery of fuel, repairing a flat tire, jump-start the automobile, or towing to a service station.

2. A Personal Emergency Response (PER) service which will provide subscribers with the ability to request emergency equipment and personnel immediately upon request from their vehicle without knowing their exact location. Examples of scenarios where this service is envisioned to be useful include sudden extreme illness of the subscriber (requiring an ambulance), automobile fire (requiring a fire extinguisher), or an accident (requiring police assistance). In addition, a panic button allows a user to call for police in cases where a user feels endangered in or near the automobile.

3. A Vehicle Tracking Assistance (VTA) service which will be designed to maintain the most up-to-date, accurate location of the automobile, and truck, possible without the aid of the driver. The primary application of the VTA service is in the theft/automobile security arena. When a subscriber's automobile is stolen or car-jacked, maintaining the current location of the automobile is critical to recovery, and could be of great

assistance to the police. It can be used to track trucks carrying commercial cargos, taxis, etc.

4. A Traveler Information Assistance (TIA) service which will enable subscribers to acquire information on a variety of destinations from the comfort of their automobile. The types of destinations about which information such as name, address, and phone number will be provided include banks, ATMs, restaurants, service stations, and hotels/motels. The subscriber will receive assistance in selecting the optimal destination, and also can be given detailed directions from the current automobile location to the selected destination.

5. A traffic Incident Management (TIM) service which will assist subscribers in reaching their destinations as quickly as possible and alert travelers to traffic conditions in the area they are traveling or typically travel. Such a capability will be provided by devising a route based on the time of day, day of the week, and the current traffic conditions, including both static and dynamic conditions. These three factors can affect the traffic volume on a road, the turn restrictions to/from a road, the speed limit on a road, and the direction of traffic (one-way or two-way) permitted on the road. In addition, weather, as it affects traffic and driving conditions will be utilized in providing TIM service.

BACKGROUND AND BRIEF DESCRIPTION OF THE INVENTION:

The current cellular telephone system provides a means for people to gain access to a variety of services (described above) that can be obtained via the public switched telephone system. However, the ability to provide service to people in this system is severely limited by the fact that a mobile user does not have a fixed address which enables a service provider to locate the customer and supply the requested service. The critical missing element that is lacking is the automatic determination of the geographical position (in latitude and longitude) of a mobile user that serves as the address of the mobile. This element is integrated into the invention via a novel technique for rapidly

deriving precise position estimates via the GPS system in obstructed environments. In addition, the invention described herein also provides for the automatic relay of the derived position estimate to a service provider whenever a person calls and connects with a service provider that has communications equipment compatible with the mobile. Such equipment, described herein, supports the simultaneous transmission of voice and data over a single telephone channel in the cellular telephone network.

Most modern GPS receivers employ the GPS satellite almanac and rough information on current time and position to attempt to acquire signals of visible GPS satellites by searching in a limited number of frequency bins over a time uncertainty hypothesis of one millisecond, the repetition interval of the GPS C/A codes. The terms "frequency bin" or "frequency cell" (used interchangeably herein), mean a narrow frequency range or spectrum, each frequency bin or cell having a characteristic center frequency and a predefined width or band of frequencies. In general, the entire sequence of events for arriving at a estimate of position location is in accordance with the following sequence of events:

1. Detection of a satellite PN code in a frequency bin,
2. Acquisition and tracking of the carrier frequency,
3. Acquisition and tracking of the data transitions and data frame boundary,
4. Reading broadcast data for the satellite ephemeris and time model (the 900 bit Satellite Data Message),
5. Completing steps 1-4 (serially or in parallel) for all in-view satellites,
6. Making pseudorange measurements on these signals in parallel, and
7. Computation of position using the pseudorange measurements and satellite data.

The time required to accomplish these steps in a conventional GPS receiver will vary depending upon the assumed

starting point of the GPS receiver. It is useful to define three reference starting points for a GPS receiver. These are as follows:

Cold Start: Where the receiver has no GPS almanac. The GPS almanac is a 15,000 bit block of coarse ephemeris and time model data for the entire GPS constellation. Without an almanac, the GPS receiver must conduct the widest possible frequency search to acquire a satellite signal. In this case, signal acquisition can take several minutes to accomplish because a large number of frequency cells must be searched that takes into account the large uncertainties in satellite Doppler as well as GPS receiver oscillator offset. In addition, acquisition of the GPS almanac will take at least 12-1/2 minutes of listening to the broadcast of a single GPS satellite.

Warm Start: Where the receiver has a GPS almanac to aid the acquisition of satellite signals by greatly reducing the uncertainty in satellite Doppler and therefore number of frequency cells that must be searched. In this case, the number of frequency cells that must be searched is determined by the accuracy of the GPS local oscillator. For a typical oscillator accuracy of one ppm, the frequency search can be accomplished in less than 10 seconds. In this case, the major time bottleneck for generating a position fix is the time required to acquire the 900 bits of the Satellite Data Message for each GPS satellite that is to be used in computing the receiver position. This Message is broadcast every 30 seconds at 50 bps. For parallel GPS receiver channels, the time requirement to obtain the 900 bit Message from each in-view satellite is roughly 30 seconds.

Hot Start: Where the receiver already has the Satellite Data Messages for all the in-view GPS satellites (7200 bits for eight satellites). In this case, the major time bottleneck is the acquisition of multiple satellite signals and generating pseudorange measurements from them (steps 6 and 7 above). The condition of a GPS receiver is "hot" if it recently (minutes) traversed the steps 1 - 5 above, or if it received the Satellite Data Messages from an alternate source. From a hot start, position determination begins at steps 6 and 7. This can be accomplished quite rapidly if a pseudorange measurement is utilized to calibrate out the frequency uncertainty of the GPS receiver oscillator, thereby enabling the rapid acquisition of subsequent satellite signals with a search over only a single frequency cell. Thus, from a hot start, it is possible to achieve a position fix very rapidly (in less than one second) if a search algorithm is used that minimizes the required frequency search band for signal acquisition.

This invention merges GPS position location and wireless data communication technologies to achieve a precise position location via GPS in the urban canyon and other line-of-sight obstructed environments. A multi-channel GPS receiver with the capability to simultaneously track (and make pseudorange measurements with) all in-view GPS satellites is used in conjunction with an algorithm that makes maximum use of all a priori information about the GPS receiver (its oscillator bias, its location, its knowledge of time) and the ephemeris and time models of the GPS constellation received by a wireless data communication channel or link to enable rapid acquisition of the GPS signal.

As shown above, currently, there are two time bottlenecks in estimating accurate position via GPS. One of these is due to the

oscillator bias of the GPS receiver which is a driver for a time consuming search over many frequency cells.

According to the invention, the search over frequency is required only for the acquisition of the first GPS satellite. The frequency measurement from tracking that one satellite is then used to calibrate out the frequency bias of the GPS local oscillator. Thus, the subsequent acquisition of other GPS satellite signals can be accomplished very rapidly because the number of frequency cells that must be searched is reduced to one.

The second time bottleneck in determining precise position location is the necessity to read the 900 bit GPS Satellite Data Message block containing the ephemeris and satellite clock models of the GPS satellites. This data message must be extracted for each satellite that is used for the GPS position solution. Extracting this needed information for determining position will take 30 seconds in a clear environment; in an obstructed environment, extracting this information may take far longer, and in the worst case, may not be possible at all.

According to the invention, this is supplied to the GPS receiver with the needed ephemeris and satellite clock information via an independent wireless data channel such as can be supported by an RDS FM broadcast or a cellular telephone channel. With a cellular telephone, the needed data can be supplied by calling (or receiving a call from) a service center and establishing a data link via a modem in the cellular phone, and a modem to a service center. The required GPS satellite information is then supplied via the established data link. At typical modem speeds (300 bps to 19.6 Kbps), this information is supplied in only several seconds to less than one second, depending upon the modem speed. In this manner, the GPS is assisted in rapid signal acquisition and rapid determination of position, even in obstructed environments.

In addition to an improved algorithm for rapidly determining position via GPS in an obstructed environment, this invention

also solves the problem of establishing the required data link with the GPS receiver. The primary method discussed herein utilizes a mobile cellular phone channel to support a data and a voice channel at the same time. According to the invention, this is accomplished by taking a frequency notch (say 600 Hz, for example) out of the audio band and embedding a data channel in this notch. A 300 bps half-duplex channel can be achieved via a frequency shift keyed (FSK) system with two tones in the frequency notch. With the appropriate notch filter, the participants in the voice conversation hear no modem tones associated with the transfer of data. Preferably, the notch filtering is digitally implemented. There is of course some degradation to the voice quality, depending upon the size and shape of the frequency notch, and its center location. For example, with a notch placed between 1500 Hz and 2100 Hz, voice intelligibility is excellent, and voice recognition is good. With such a frequency notch, a 300 bps "data-in-voice" modem with FSK tones at 1650 Hz and 1959 Hz can be implemented.

A further embodiment of the invention incorporates a recliner for monitoring local radio stations and determining position from the signalling geometries of a plurality of local stations, and a circuit detects GPS outages or black-outs and enable the use of local radio broadcasts for position determination or finding. In a preferred embodiment, local AM radio broadcasts are used with the data channel in the cellular phone being used.

DESCRIPTION OF THE DRAWINGS:

The above and other objects advantages and features of the invention will become more apparent when considered with the following specifications and accompanying drawings wherein:

Figure 1 is a chart illustrating prior and warm start sequence of events in a GPS system,

Figure 2 is a chart illustrating the warm start sequence according to the invention,

Figure 3 is a schematic illustration of how a priori knowledge of position resolves the ambiguity in time-position,

Figure 4 is a flow chart of signal processing according to the invention,

Figure 5 is a block diagram of GPS receiver combined with a cellular telephone and a controller according to the invention,

Figure 6 is a block diagram of the data-in-voice modem according to the invention,

Figure 7a is a block diagram of a configuration for the invention that interfaces with existing cellular phone equipment that may already be installed in the vehicle, and FIG. 7b illustrates how this can be done with a wireless connection,

Figure 8 is a block diagram of the enhanced cellular telephone services provides by the invention,

Figure 9 is a block diagram of the customer service center disclosed in Fig. 8,

Figure 10 is a block diagram of a system modification incorporating position determination using the position geometries of commercial radio broadcasting stations in conjunction with a local reference station, and

Figure 11 is a block diagram of a receiver for deriving signals used in the microprocessor for this alternate position finding.

DETAILED DESCRIPTION OF THE INVENTION

Figure 1 illustrates the sequence of events and the time requirements to estimate the position via a typical GPS receiver from a warm start. From a warm start, the first step in the process is the reading the GPS Satellite Data Messages contained in the broadcast signals of each satellite. This proceeds with the acquisition of the signals from all in-view satellites (which may take up to 10 seconds). Acquisition begins with PN code acquisition and proceeds to move through the processes of detection confirmation, PN tracking, frequency locked loop pull-in, conversion to phase lock for data demodulation, followed by bit and frame synchronization. Within 40 seconds after a warm

start, the receiver will typically have extracted the necessary satellite ephemeris and clock data in the Satellite Data Message of each satellite (i.e., if no obstructions are presented). For a receiver that is presented with obstructions, the time required to collect the necessary data can be quite long. GPS data is transmitted in 1500 bit frames at 50 bits per second. Thus, each frame is transmitted in 30 seconds. The 1500 bit frame of each broadcast is composed of five subframes of 300 bits length. The first three subframes of a broadcast signal (900 bits) comprise the Satellite Data Message for the broadcasting satellite. The Satellite Data Message contains precise ephemeris and time model information for that satellite. The first three subframes are identically repeated in each 1500 bit frame, except that the information is updated periodically. The fourth and fifth subframe contain a part of the almanac which contains coarse ephemeris and time model information for the entire GPS constellation. The contents of the fourth and fifth subframes change until the entire almanac is sent. The repetition period of the fourth and fifth subframes is 12-1/2 minutes and so the entire GPS almanac is contained in 15,000 bits. The subframes are composed of 10 words of 30 bits length with Hamming (32, 26) parity concatenation across words. This means that the last two bits of the previous word are part of the 26 bits used to compute a six bit syndrome. Therefore, it is necessary to receive all 32 bits of each word without interruption.

The invention removes the two greatest time bottlenecks discussed above in determining position via the GPS system. One bottleneck is eliminated by providing the GPS receiver with the needed Satellite Data Messages of the GPS constellation via an external data link supported by the cellular channel. The Satellite Data Messages for eight in-view satellite will be contained in 7200 bits or less; thus, with an external link at data rates from 300 bps up to 19.2 Kbps, the time required to transfer the needed Satellite Data Messages will take from several seconds to only a fraction of a second. The second

bottleneck that the invention eliminates is the time required to acquire the signal from subsequent satellites after the first satellite is acquired. It accomplishes this by an algorithm that optimally using GPS ephemeris and time model data together with the Doppler measurement on a single satellite signal to calibrate the GPS receiver frequency reference and thereby reduce the frequency uncertainty (and therefore the time required) for acquisition of subsequent satellite signals.

Figure 2 illustrate the general strategy and algorithm for a GPS receiver capable of rapid acquisition. While the embodiment discussed herein assumes an eight-channel receiver capable of simultaneously tracking all "in-view" GPS satellites, it is clear that more satellites could be used. The start of any position determination via GPS is normally the acquisition of the signal from the "in-view" GPS satellites in order to read the Satellite Data Messages. However, in this case, the current Satellite Data Message of the GPS constellation are first requested and received via an independent link such as a data link supported by the cellular telephone system. As soon as the first satellite is acquired, the pseudorange and Doppler are measured. Using the Doppler information from this measurement allows subsequent satellites to be rapidly and reliably acquired and reacquired as the mobile host vehicle progresses through obstructed fields of view.

According to the invention, at the acquisition from a warm start-up, the receiver's oscillator offset is the dominant factor in determining the frequency error of uncertainly (f_e) of a broadcast GPS satellite signal. The GPS receiver has either a user-entered, or integral timing function, which is accurate to t_e. Using this local time value, the receiver employs a GPS satellite almanac which was previously collected, or was injected via a data port to estimate which GPS satellite is most directly overhead. This computation produces an estimate of the line-of-sight Doppler offset of the GPS L1 carrier frequency relative at

the fixed at the location of the GPS receiver. The frequency search aperture is the sum of error in this line-of-sight Doppler offset estimate, the Doppler offset due to motion of the user vehicle, and the offset of the GPS receiver local oscillator scaled to the L1 carrier frequency. For a t of one minute, the error in the estimated offset will typically be about 60 Hz. If the user velocity is assumed to be less than 30 meters per second, this will produce an additional 76 Hz frequency uncertainty. (With the velocity vector principally in the local tangent plane, its contribution to the search aperture is 150 Hz times the cosine of the elevation angle to the satellite which presumably is above 60 degrees, thus reducing the offset by half.) The crystal oscillator is presumed to have a one ppm accuracy, giving an offset of ± 1580 Hz when scaled to the L1 frequency. This results in a total frequency uncertainty of roughly ± 1700 Hz around the computed Doppler offset.

The C/A code can be searched at a rate of 1000 chip timing hypotheses per second per correlator per channel for a detection probability of 0.95 and a false alarm probability of 0.01 assuming a 40 dB-Hz C/kT. Typically, triple correlator (early, punctual, and late) spacing is 1.5 chips or less. Thus a specific C/A signal can be searched in one Doppler bin of 500 Hz width in one second or less. There are seven bins in the 3500 Hz frequency uncertainly band (each 500 Hz wide) thereby requiring a total search time of seven seconds to acquire the first signal. However, if an eight-channel receiver is used to acquire a chosen overhead GPS satellite, all frequency cells can be searched simultaneously and the satellite signal can be acquired in one second. Upon acquisition of the signal, the signal is tracked, and a measurement of pseudorange and Doppler is obtained. This convergence requires less than 4 seconds.

This Doppler measurement is then used to collapse the frequency uncertainty in acquisition of subsequent satellite signals by calibrating the GPS local oscillator against the Doppler measurement. The acquisition frequency uncertainty band

is then reduced to the sum of the uncertainties of the ephemeris data and the vehicle Doppler, or less than a few hundred Hz. Consequently, subsequent satellite signal acquisitions can be accomplished in only one second via a search over only a single 500 Hz frequency cell. Thus, with an eight-channel receiver, all in-view satellites can be acquired in parallel in only one second, and pseudorange measurements can be generated in an additional 1/2 second. Until the data frames from at least one GPS satellite are read, the above measurements contain a time-range ambiguity equal to the period of the PN code (1 msec-300 km). If time framing for only one satellite signal is established, this time-position ambiguity is resolved. As mentioned above, reading the required data frames on the broadcast signal will require roughly 30 seconds. However, this time bottleneck can be avoided as long the a priori position uncertainty is sufficiently small to resolve the ambiguity. The requirement will, in general, depend upon the GDOP of the in-view GPS constellation, but it is clear that the assumed a priori assumption of 10 km will be more than sufficient to resolve the ambiguity. Thus, position location is possible without ever taking the time to read the GPS data. In summation, with the invention that starts with providing the GPS receiver with the needed Satellite Data Messages via an external data link, the position may be determined in less than three seconds.

Figure 3 illustrates how the a priori knowledge of position resolves the ambiguity in time-position. It pictures a cylindrical start-up position uncertainty volume of height $2v_e$ and radius r_e. Here, v_e denotes a bound on the uncertainty in altitude relative to the WGS-84 geoid and r_e denotes a bound on the radial uncertainty in position from a known point in the plane tangent to the geoid. At start-up, the receiver is somewhere within this uncertainty cylinder, and the receiver's software assumes that it is located at the center of the cylinder. The uncertainty cylinder determines the ability of the

a priori position knowledge to resolve the time-position ambiguity of the GPS receiver. In the worst case situation, the uncertainty cylinder will result in an uncertainty corresponding to a distance of $v_e^2 + r_e^2$. If one assumes a value of 10 km for this quantity, the resulting local clock uncertainty will be about 30 microseconds. In general, based upon pseudorange measurements with the in-view satellites, there will be a number of GPS receiver time-position pairs that are consistent with these pseudorange measurements). However, only those solutions contained inside the position uncertainty cylinder and the time uncertainty window (one minute assumed) can be real solutions. And it is clear that as long as the uncertainty cylinder is not large, there will only be one time-position pair in this region so that the solution is unique and the ambiguity is resolved.

Subsequent to resolving the time ambiguity of the GPS receiver, acquiring satellites can be further aided by the reduced time as well as frequency uncertainties. With a one ppm GPS receiver clock drift, time can be maintained to better than 60 microseconds, even with the receiver outages lasting up to one minute. Thus, the required PN search to acquire a satellite can be reduced to a search over less than 100 C/A code chip positions. The frequency uncertainty is still much less than a 500 Hz cell. Thus, it should be possible to acquire subsequent satellite signals in 0.1 seconds by searching 100 code chip phases in a single frequency bin. A measurement of pseudorange using code phase under condition of frequency lock can be made in an additional 0.5 seconds. Thus, once the GPS receiver time and frequency are calibrated, it is possible to acquire and generate pseudorange measurements from multiple satellite signals in parallel in less than one second. Thus, in this reacquisition mode, the time required for position location is indeed quite short. In situations where signals are obstructed by tall structures except at the crossroads, this is the only way that a GPS position fix can be generated. The search process for

multiple satellite signals is repeated endlessly, and acquisition of multiple satellite signals will occur whenever the view to multiple satellites is unobstructed. The detailed logic of the algorithm for rapid GPS signal acquisition is illustrated in Figure 4.

Figure 5 illustrates a preferred embodiment or configuration which includes a GPS receiver 20 combined with a cellular telephone 21, having a primary cellular antenna 21A1 and a hidden parallel cellular antenna 21A2 that is capable of supporting the rapid acquisition capability of the GPS signals, and rapid determination of position. The GPS receiver 20 has an in-dash antenna 20A1 and a roof or exterior antenna 20A2 and a plurality of parallel channels CH...CHn for independent attempts at acquiring multiple (sight in this embodiment) satellites simultaneously. This is required since it is important that the acquisition process for the first satellite can search the entire frequency uncertainty region in parallel. Given that the state-of-the-art oscillators for GPS receivers have a frequency accuracy of about one ppm, this requires at least seven parallel channels to encompass the frequency uncertainty band. When oscillator frequency accuracy improves, then the preferred number of parallel channels can be reduced. The eight-channel receiver is also important for rapid acquisition in parallel of all in-view satellites. With an eight-channel receiver, all in-view satellite signals will be searched for; thus as long as the line-of-sight to a given in-view satellite is not blocked, its signal will be typically acquired in less than one second with a rapid acquisition receiver. The GPS receiver 20 is under the control of the controller element 22 shown in Figure 5, which includes a microprocessor controller 30, "data-in-voice" modem 31 (see Fig. 6), and autodialer 32.

The first step in using the unit to determine the position via GPS would be for the controller to acquire the Satellite Data Messages for the in-view GPS satellites. In one embodiment, this is provided by intercepting a broadcast signal such as the RDS in

the FM radio band, or by calling a service center 40 and establishing data link with a compatible modem. The current ephemeris and time models of the GPS satellite constellation stored in the GPS satellite almanac database 41 would then be provided to the unit via that data link - the cellular telephone system 42. This link would also provide GPS correction parameters that support much improved GPS position accuracy when the GPS is in the search and acquisition mode. The controller 22 would thus obtain the Satellite Data Messages of in-view Satellites, and route this data to the GPS receiver 20 where it would be used to support the acquisition of the first overhead satellite, support the subsequent acquisition of all in-view satellites, and calculate the position of the receiver, based upon subsequent pseudorange measurements with these satellites. A memory power is supplied to controller 22 to maintain data stored therein.

The system shown in Fig. 5 also includes a cellular telephone handset 50, a cradle, and an RF pushbutton device 54 for theft alarm enable/disable initiation, and the RF interface 55 for that device to controller 22. The handset has all the controls (not shown) needed to initiate and receive calls from the telephone system, but the installed unit in the vehicle acts as relay station to the cellular system 42. The handset 50 serves as the interface for voice input and audio output for the vehicle user. The controller 22 mediates the transmission of voice and data over the common cellular telephone channel. The RF pushbutton device 54 is used to enable/disable a theft reporting function of the vehicle unit. This function is to autonomously initiate a call when a defined theft condition is realized and to accurately relay the vehicle position as determined by the GPS receiver 21.

One example of such condition is whenever the system receives battery power with the theft reporting function in the enabled state. The pushbutton device 54 (which may be called a "panic button") is packaged in a small keychain type unit similar

to those for alarm enable/disable of current vehicle theft alarm equipment. The panic button 54 may also be a two-way communication device that will operate as follows: the user, upon pressing the panic button will send an RF signal that will be received at the vehicle receiver interface 53; the receiver 55 will then send an acknowledgement to the user-held panic button 54 via an RF signal; the user will be informed that an acknowledgement is sent via an inaudible vibration 54IB of the panic button 54 when an acknowledgement is received.

In addition to an improved algorithm for rapidly determining position via GPS in an obstructed environment, the present invention also solves the problem of establishing the required data link with the GPS receiver. The primary method of this embodiment utilizes a mobile cellular phone channel to support a data and a voice channel at the same time. This is accomplished by taking a 600 Hz frequency notch out of the audio band and embedding a data channel in this notch. A 300 bps half-duplex channel can be achieved via a frequency shift keyed (FSK) system with two tones in the frequency notch. With the appropriate notch filter, the participants in the voice conversation hear no modem tones associated with the transfer of data. Degradation to the voice quality is low, depending upon the size and shape of the frequency notch, and its center location. It has been found that with a 600 Hz notch placed between 1500 Hz and 2100 Hz, voice intelligibility is excellent, and voice recognition is good. With such a frequency notch, a 300 bps "data-in-voice" modem with FSK tones at 1650 Hz and 1959 Hz can be implemented.

Figure 6 illustrates the block diagram for the data-in-voice modem contained in controller 22. A digital implementation of this algorithm using a commercially available digital signal processing (DSP) chip is within the scope of this invention. In Fig. 6 note that processing and filtering is implemented on both the transmit and receive channels.

The transmit channel 100 includes filter delay line 101 feeding bandstop filter 102 so that a notch (600 Hz, for example)

is subtracted from the voice or audio band and a tone generator 103 inserts the two FSK tones (1650 Hz and 1959 Hz, for example), of the data channel into this notch via summer 104. The receiver channel 105 is similarly filtered by filter delay line 106 and bandstop filter 107 creating separate outputs 108 and 109-H and 109-L of the filtered voice, the high tone bandpass 110, and the low tone bandpass 111. A comparison and smoothing operation on the bandpass signals in the data decisions circuit 114 results in the received data stream 115. In addition to the processing of the transmit and receive channels, the "data-in-voice" modem has two digital inputs 112 and 113 from microprocessor 30 (Fig. 5) for mode control: one enables/disables the channel filtering, and the other toggles the modem between its transmit and receive modes.

In addition to combining data and voice on a single audio channel, the data-in-voice modem 311 (Fig. 6) also samples and compares the incoming and outgoing voice power during hands free operation. In hands-free mode (microphone/speaker phone in Fig. 5), incoming voice is broadcast from the cradle speaker and outgoing voice is picked up by the microphone. One way of avoiding feedback and echoes in this configuration is to severely attenuate one of the voice signals (i.e. the weaker) so that the voice conversation is half duplex. It is important to do this attenuation on the audio signals before the transmit data has been put on (for the outgoing audio), and after the receive data has been stripped off for the incoming audio. By implementing the processing in this manner the data-in-voice modem is fully compatible with hands-free operation of the cellular telephone: that is, data transfer will not be affected by the voice conversation, and neither will the voice conversation be affected by data transfer.

This system for combining data and voice on the same cellular telephone channel is advantageous in that there is (1) blanking of the voice channel, (2) no audible tones to the users involved in a voice conversation, and (3) little degradation to

speech quality.

Configurations for retrofitting existing cellular phones with the invention are shown in Figs. 7a and 7b. As diagrammatically illustrated in Figs. 7a and 7b, a trunk mounted cellular phone transceiver unit and controller, model and GPS unit is coupled to the existing cellular phone components by a RJ cable, whereas in Fig. 7b, they are coupled by an RF link. The retrofit configuration shown in Fig. 7b requires a conventional wireless add link between the trunk mounted components and the existing cellular phone components (cradle and handset) in the passenger compartment of the vehicle.

This invention provides the most rapid and robust position location system possible via the GPS constellation. Novel aspects of the above system include the use of an external data link to the GPS receiver to rapidly provide the Satellite Data Messages, and the efficient system and method that optimally uses this information to rapidly acquire all in-view satellites.

An embodiment of a Position-Enhanced Cellular Service Systems (PECS) system is shown in Fig. 8. The two main PECS elements are the Vehicular Applique Unit 120 and the customer Service Centers 121. The elements are shown in this diagram as "applique" features to the existing Cellular Service which require no modification to or interference with the existing Cellular System: the Vehicular Applique Unit (VAU) 120 replaces the existing vehicle cellular phone, and the Customer Service Center 121 connects with the Cellular System 123 via the existing switched telephone system 122. Because of the present implementation of this "applique" concept, the enhanced services can be provided on any Cellular System, making the system "portable" to other service areas. Furthermore, because of the "open architecture" concept, other services can be accommodated, thereby providing an enormous potential for a variety of revenue-generating specialized commercial services. Functionally, VAU 120 may be packaged in a hand-held device and include a key pad (not shown) for programming. In addition, a digital recorder

chip for recording voice digitally in VAU 120 and playing back to the user of the cellular telephone can be easily incorporated in the unit. The system offers a number of unique and attractive features such as:

1. Vehicle position updates as often as every 2 seconds to support real-time routing.

2. Novel data-in-voice modem that simultaneously supports a 300 bps continuous positioning data channel and a voice channel via a single cellular telephone call.

3. Exterior Primary cellular and GPS antennas for robust performance in all environments.

4. Switched Failover to hidden cellular and GPS antennas for Vehicle Tracking (in case a thief disables the primary antennas).

5. Fleet management is a further application of the invention whereby an operator of a fleet of maintenance vehicles or taxis can keep track of the position of all vehicles in the fleet in order to optimally assign the vehicles to tasks at a given location.

A key value-added feature of the PECS concept that differentiates it from other systems is the ability to accurately determine the vehicle's ephemeris data (position, heading, and speed). The system incorporates the use of the Global Positioning System's NAVSTAR Satellite constellation to provide the most accurate, freely-available, and worldwide navigation data distribution system. An eight-channel GPS receiver (capable of differential operation) is preferably used in the baseline Vehicular Applique Unit in order to provide a consistent accuracy that can unambiguously identify vehicle location by street address and determine on which side of a major highway the vehicle is positioned.

Figure 9 illustrates the configuration of a Customer Service Centers (CSC) 130, 131, 132... 13n for the Positioned-Enhanced Cellular Services System shown in Fig. 8. Each CSC 130, 131, 132...13n is comprised of four subsystems which allow it to

perform its activities. Those subsystems are the Communication and Switching Subsystem 133, the Administration and Maintenance (A&M) Subsystem 134, the Position Processing Subsystem 135, and the Service Provisioning Subsystem 136.

The Communication and Switching Subsystem 133 includes the hardware and software required to interface the CSC with the public switched telephone system 122 for the receipt of incoming calls and the transmission of outgoing voice and data to the subscriber and the subscriber's vehicle. The Communication and Switching Subsystem also interacts with the A&M Subsystem to ensure that a subscriber's voice and data links are routed to the same service representative position (SRP) within the Service Provisioning Subsystem 136.

The A&M Subsystem 134 performs all CSC tasks related to system administration and maintenance. An example of an administrative task executed by the A&M Subsystem is the assignment of an incoming call to the optimal SRP, based on criteria such as SRP loading and service representative profiles. An instance of a maintenance task would be the near-real-time maintenance of mapping and Yellow Pages databases.

The Positioning Subsystem 135 has the responsibility of interfacing with an on-site or remote GPS reference station 137 for the purpose of receiving differential correction coefficients. The differential correction coefficients ultimately will be passed to the VAU in a subscriber's vehicle. The delivery of the differential correction coefficients to the vehicle allows the position of the vehicle to be determined to a high degree of accuracy (to within ten meters).

The Service Provisioning Subsystem 136 allows service representative to speak directly with subscribers to determine the exact nature of service requirements. The Service Provisioning Subsystem is comprised of the hardware and software via which the service representatives can access mapping, routing, Yellow Pages, and user profile data in order to provide responses to the subscriber as quickly and accurately as

possible.

Another embodiment and feature of the invention is that it can include receiver means for monitoring local AM radio stations to augment GPS signals when receipt of GPS signals is impaired or rendered unreliable by the urban environment. Referring to Fig. 10, AM receiver 220 has antenna 221 for receiving the AM signals broadcast by stations AM1, AM2...AMN and provide the phase measurements for which are used to determine position, as described later herein in connection with Fig. 11. AM receiver 220 provides phase measurements to microprocessor 223, which is coupled to digital data storage base 224, which has stored therein the frequency and physical location of all of the AM radio stations of interest for the area. Any drift in these AM station frequencies is corrected in microprocessor 223 by data received from the local reference station 211 via the customer service center 213, cellular network 216, and the cellular telephone 225.

In order to resolve any ambiguities in the AM radio positions, and accommodate the lack of synchronization among the AM stations, the most recent accurate GPS position data from GPS receiver 226 is provided to microprocessor 223 for storage in storage 224.

Outside of urban canyon areas positioning via GPS will almost always suffice. Within urban canyons (e.g., downtown Manhattan) considerable blockage from tall buildings TB can dramatically reduce GPS satellite visibility. Within these same urban canyons, however, a significant number (e.g., 5-10) of strong AM signals will be simultaneously available; furthermore, these signals can "surround" the vehicle 210, thereby yielding excellent signaling geometries for positioning. Within the framework of Fig. 10, the invention may be described as follows:

1. Outside the urban canyon, GPS 226 provides the vehicle with regular, accurate position updates, as described earlier.

2. The local Reference Station 211 shown regularly receives signals from all local AM stations of interest and measures key

parameters (e.g., frequency and wavelength variation), that are provided to customer service centers 215 and then to vehicles via the cellular network and serve as differential corrections. AM signals are passively received -- i.e. asynchronously, and with no coordination with the AM Stations. With proper site selection, and utilization of a suitable, low-cost clock reference (e.g., 1 part in 10^{10}), this Reference Station 211 can be established and maintained very cost-effectively; for example, they do not have to be mounted on an expensive tower. The reference station also collects data from the GPS satellites in order to generate GPS differential data. This data is also provided to the vehicles via the customer service centers and the cellular phone link described earlier.

3. As the vehicle approaches the urban canyon TB, the vehicle receives local AM signals from stations AM1, AM2, AM3...AMN, and associated differential corrections from the Reference Station 211. The vehicle contains a digital database 224 that includes the frequencies and locations of all local AM stations of interest. In this embodiment, AM signals are not used for positioning as long as GPS is providing reliable position.

4. The vehicle 210 continues its positioning process via GPS until a GPS blockage or outage is detected by detector 227. At the onset of a GPS outage, the vehicle's positioning system contains an accurate GPS position estimate that serves as the starting point for the AM positioning process. The accuracy of this initial position estimate is on the order of 100'. Since this is a fraction of an AM wavelength, it can serve as the basis for an unambiguous pseudorange estimate for each AM signal that is being received. The AM wavelength is a critical and highly attractive ingredient of this aspect of the invention, given its amenability to a priori ambiguity resolution and its subsequent amenability to highly accurate tone ranging (see below).

5. The AM positioning process involves incremental, differential range measurements via tone ranging of the AM carriers. The process, illustrated in Fig. 11, includes the following:

a. At least three, and preferably four or more AM signals (F_1, F_2, F_3 and F_4) are simultaneously received, split by power splitter 230, and sampled in each AM RF processor 235-1, 235-2, 235-3, and 235-4 at 0.5 second (TBR) intervals. This sampling interval is selected because even at a speed of 100 ft/sec (>60mph), the incremental distance the vehicle travels is a small fraction of an AM wavelength. This is important to ensure that no AM wavelengths are "skipped" from one sampling interval to the next. Also, while a minimum of three simultaneous AM signals are required, more than three can be used to enhance accuracy and/or ensure that the strongest, highest quality AM signals are being employed.

b. The incremental phase of each AM carrier -- relative to the previous measurement -- is measured, and corrected for phenomena such as carrier frequency drift via the corrections provided by the Reference Station, via the cellular telephone network.

The measurement process sequence is as follows:

- The incremental Phase = $\phi_{12} - \phi_{11}$ (Radians)
  $\Rightarrow$ Incremental Range = $\lambda_1[(\phi_{12} - \phi_{11})/2\pi] = \Delta R$
  $\Rightarrow$ Estimate of New Range at t_2, $R_{12} = R_{11} + \Delta R$

- Simultaneous Computations for 3 other AM signals Yield New Range Values:

  R_{22}, R_{32}, $R_{42} \ldots R_{N2}$

- Differenced Ranges Formed: $R_{22} - R_{12}$; $R_{32} - R_{12}$, ..$R_{N2} - R_{12}$
  - Differencing Eliminates Vehicle's Local Clock Error

- Set of Differenced Ranges Processed to Yield Updated Position

- Process Repeats Every 0.5 sec (TBR)

This phase measurement process reflects the high-accuracy tone ranging process that is uniquely accommodated by the judicious wavelength of the AM waveform. In particular, for a representative 1 MHz AM carrier and a corresponding ~1000' wavelength, a phase measurement accuracy on the order 1 degree -2 degrees yields a corresponding range accuracy of 3' - 6'! An exemplary embodiment of a robust implementation approach for this phase measurement process is described later herein.

c. As indicated above, each incremental phase is normalized and multiplied by its respective wavelength to yield an incremental range value, which is then added to the previous value of total range to yield an updated estimate of total range.

d. The resulting set of at least four range values are used to form a set of at least three corresponding differential range values. This differencing process effectively eliminates the vehicle's clock as an error source in the positioning process.

e. Based on the above, at each 0.5 second interval, the set of differential range values are used to compute a new position estimate.

6. Throughout the above process, the vehicle's GPS receiver continues to operate and to ascertain the quality of the received GPS signals. Once GPS quality is resumed, handover from AM - to - GPS positioning takes place. Furthermore, while the above process addresses AM processing only, the invention contemplates

and encompasses hybrid approach of processing both AM and GPS signals simultaneously. This should enhance the urban canyon positioning process, since even in the urban canyon at least one GPS signals should always be available with high probability.

DESCRIPTION OF AM SIGNAL PROCESSING APPROACH:

Implementation of the invention depends on a robust, low-complexity approach to measuring the incremental phases of several AM signals simultaneously. In one embodiment, signal processing that accomplishes the above is illustrated in Fig. 11 This processing approach is employed by each vehicle, and also by the Reference Station to accurately measure reference values for transmission to each vehicle. The following is noted:

1. Because of its low frequency, each AM signal may be sampled and A/D converted in A/D converter 241 directly at RF without downconversion. As illustrated, the sampling and phase measurement process employed is "open-loop". This has the distinct advantage of not being susceptible to short-lived channel transients -- such as impulsive noise arising during a thunderstorm. Thus, in contrast to a closed-loop process, which may lose lock during such an impulsive transient, the embodiment of Fig. 11 would only yield a phase measurement "glitch" due to the transient, which is easily recognizable, and can be discarded; crucial, however, is that the integrity of the sampling and phase measurement process would be maintained.

2. The sampler 240 has the sampling rate shown -- i.e., at 4 times the carrier frequency -- and is selected so that successive samples are precisely 90 degrees apart, which are thus effectively in-phase (I) and quadrature (Q) samples of the AM carrier sine wave. As has been discussed earlier, the AM frequencies of interest are resident in the vehicle's digital memory 224, and precise frequency information is available via corrections provided by the Reference Station 211. Also high sampling accuracy -- to a small fraction of a Hz -- is readily achievable via low-cost, existing digital frequency synthesis technology. In fact, the multi-channel digital processor shown

in Fig. 11 is readily amenable to miniaturization in an Application Specific Integrated Circuit (ASIC).

3. The multiplicative sequencer 242 shown after the A/D converter 241 appropriately rectifies the negative-going I and Q samples, so that the two-stage accumulator 243 that follows can filter out all other AM signals and yield averaged, SNR-enhanced I and Q samples 244. This sampling and averaging takes place for ~ 1 ms every 0.5 seconds. For the strong AM signals of interest, this 1 ms interval will be more than adequate for SNR enhancement. Furthermore, in 1 ms the AM carrier phase will vary negligibly due to vehicle motion (e.g., <0.05 degrees) for a 1 MHz AM carrier and a vehicle moving at 100 ft/sec.

4. The averaged I and Q samples, $\bar{I}$ and $\bar{Q}$, are then used as shown to measure phase via the arctangent function 246 or an equivalent. Note that the ratio of $\bar{Q}/\bar{I}$ automatically cancels any AM fluctuations superimposed on the desired sinusoidal waveform.

A summary of mathematical considerations is as follows:

MATHEMATICAL DESCRIPTION

- a(t) Represents AM Information; w is AM Carrier Radian Frequency; (Reflects Reference Station Corrections); wt_i is Odd Multiple of $\pi/2$
- I - Samples: $A[1+a(t_i)]\cos[wt_i+\phi] \sim A[1+a(t_i)]\cos\phi$
- Q - Samples: $A[1+a(t_i+\delta)]\sin[wt_i+\phi] \sim A[1+a(t_i)]\sin\phi$; $a(t_i+\delta) \sim a(t_i)$ for $\delta \sim 1\,\mu s$
- $\bar{I} \sim A\sum_i[1+a(t_i)]\cos\phi$; $\bar{Q} \sim A\sum_i[1+a(t_i)]\sin\phi$

Note: ϕ Varies Negligibly Over Averaging Interval (~1 ms)

$$\Rightarrow \boxed{\phi = \mathrm{TAN}^{-1}(\bar{Q}/\bar{I})}$$

This aspect of the invention introduces new capabilities, for truly global positioning, that are neither in existence nor currently planned. Further unique features of the invention include the following:

1. Global, international positioning capability (~30m, 3σ):

a. Via GPS or differential GPS outside of urban canyons, where GPS is unobstructed.

b. Via AM radio signals (or a combination of GPS and AM) within urban canyon areas, where GPS obstruction occurs and local AM signals are strongest.

2. Passive reception of GPS and AM signals:

a. Each vehicle contains database that stores all relevant AM station locations and frequencies.

b. No interaction, coordination, synchronization with GPS or AM stations.

3. A low cost Reference Station 211 is located within each required urban canyon area:

a. Measures key AM station parameters.

b. Transmits parameters to vehicles via low rate data link that employs the cellular telephone network.

4. Key operations concept ingredients:

a. Vehicle uses GPS-derived position data as unambiguous position reference prior to initiation of AM signal processing (accomplished prior to entry into urban canyon).

5. Key features/advantages of AM signal utilization:

a. The AM signal structure is simple and universal.

b. GPS a priori position accuracy is a fraction of the AM wavelength.

c. Even at high-speeds (e.g., 100 ft/sec) a vehicle's incremental position changes by a small fraction of an AM wavelength in-between position updates; this prevents large errors from occurring that may arise from "cycle skips".

d. The AM waveform includes a residual carrier that easily lends itself to highly accurate tone ranging.

e. Straightforward tone ranging processing, using sampling and high SNR phase estimation, yields range estimate accuracies on the order of 5′; this is a direct result of the AM wavelength that varies between ~600′ and 2000′.

f. The low AM frequency permits a very simplified receiver/processor, with sampling and A/D conversion directly at the incoming RF, without downconversion required.

g. Open loop processing and a reasonable update rate yield robustness against impulsive noise (e.g., lightning).

h. The relatively long AM wavelength yields a degree of robustness against multipath.

While preferred embodiments of the invention have been shown and described, it will be appreciated that various other embodiments and adaptations of the invention will be readily apparent to those skilled in the art.

WHAT IS CLAIMED IS:

CLAIMS

1. In a global positioning system (GPS) in which a plurality earth orbiting GPS satellites transmit position information to mobile radio stations on earth including a Satellite Data Message block, characterized by:

an earth based source of satellite data for all in-view GPS satellites including said Satellite Data Message blocks for each in-view satellite for assisting said mobile radio station to access position information from said satellites, and an earth based communication means coupled to said source,

means coupled to said mobile radio station for connecting to said earth based communication means to said earth- based source for extricating said satellite position data via said non-satellite earth based communication means, and

means at said mobile for processing said Satellite Data message blocks from said earth-based source to enable said mobile radio station to rapidly locate and access position information from said earth orbiting satellite.

2. In a GPS satellite positioning system in which a plurality of earth orbiting GPS satellites each transmit Satellite Data Messages, including ephemeris data and time models, said Satellite Data Messages being transmitted in a frequency uncertainty band, the method of optimally and rapidly acquiring all in view satellites, characterized by:

providing a receiver for said GPS satellite having a local oscillator,

performing a parallel search over the entire frequency uncertainty band to acquire an overhead GPS satellite,

calibrating said receiver local oscillator to reduce the frequency band for the acquisition of subsequent in-view satellites, and

performing a further parallel search for all in-view satellites using a single frequency search cell per in-view satellite.

3. In a method for determining the position of a user of a GPS receiver for receiving GPS satellite signals containing GPS broadcast data, bit sync signals and frame sync signals, characterized by, providing an independent source of a priori knowledge of receiver position to resolve ambiguity in the time position of the GPS solution.

4. In a GPS satellite positioning system for use in obstructed environments where much of the time, the line of site to most satellites is blocked and occasionally is clear, as on roads and urban areas or in heavily forested regions, characterized by, providing a GPS receiver having a calibratable local oscillator and capable of performing parallel search for acquisition of all in-view satellites, comprising:

performing a parallel search for all in-view satellites, and reducing the frequency uncertainty band for signal reacquisition to one frequency cell by calibrating the GPS local receiver oscillator on the basis of a pseudo-range measurement of one overhead satellite.

5. The invention defined in claim 1 wherein said earth-based source includes one or more dial-up service channels selected from a data link supported by terrestrial cellular telephone and other radio packet data services, and means accessing said earth-based source via one of said dial-up service channels to supply said Satellite Data Messages for all in-view satellites and said GPS receiver.

6. The invention defined in claim 5 in which said Satellite Data Message block contains ephemeris data and time models for each in-view satellite, said mobile radio station including a receiver local oscillator and means for performing a parallel search over an entire frequency uncertainty band to acquire a GPS satellite overhead and calibrating said receiver local oscillator to reduce the frequency band for the acquisition of subsequent in-view satellites, and performing a further parallel search for all in-view satellites using a single frequency search cell per satellite.

7. The invention defined in claim 5 including a basestation for a cordless cellular telephone handset, an RF control means for remote control of said handset, an RF interface mans connected to said handset to said RF control means, said handset being coupled to said GPS receiver, and modem means located in the mobile unit, whereby access to said handset provides access to the full range of capabilities, including, generation and relay of position, supported by the mobile unit.

8. In a GPS system wherein a plurality of GPS satellites transmit their respective time and location data including a Satellite Data Message block having ephemeris and time modes over radio frequency signals which enable a mobile GPS receiver on the ground receive said radio frequency signal to determine its position, characterized by: a source of satellite data message block containing the ephemeris and time modes of the GPS satellites, which is independent of said satellite, an independent wireless data channel for accessing said satellite data message block, and a controller means connecting said satellite data message block to said mobile GPS receiver.

9. The invention defined in claim 8 further characterized by said cellular telephone includes a cordless handset and further including a basestation relay means for said cordless handset for allowing remote use of said handset via said basestation relay means.

10. The invention defined in claim 8 further characterized by a pushbutton controlled RF control signal source, means for coupling control signals to said controller means to cause said mobile GPS receiver to determine its position and transmit, via said cellular telephone, the determined position to a predetermined location.

11. The global position system (GPS) defined in claim 1, further characterized by said earth based source of satellite data message block containing the ephemeris and time modes of the GPS satellites and being independent of said satellite, said mobile radio station being an independent cellular telephone

channel having a voice channel, a digital notch filter means in said voice channel for inserting and retrieving data in and from, respectively, said notch for accessing said satellite data message block and controller means connecting said satellite message data block to said mobile GPS receiver.

12. The GPS system defined in claim 11 wherein said data inserted in said notch is frequency shift keyed (FSK) data.

13. The GPS system defined in claim 11 wherein said data inserted in said notch is a plurality of discrete FSK tones.

14. In a GPS system wherein a plurality of satellites transmit time and location data over radio frequency signals to enable a mobile GPS receiver station on the ground to determine its position, and a cellular telephone carried with said mobile GPS receiver, and a plurality of conventional ground based amplitude modulated (AM) transmitters for transmitting AM signals, characterized by:

1) each mobile GPS receiver station including phase detection means for (1) simultaneously receiving a predetermined number of said AM signals, and (2) measuring the changes in phase of each of said AM signals as said mobile GPS receiver travels, and deriving therefrom an AM position signal,

2) a reference station for receiving said GPS and AM signals and providing a correction signals and a cellular telephone network for receiving and transmitting said correction signals to said mobile receiver station, and

3) means for using said GPS position signal for resolving any ambiguities in said AM radio position signal and to accommodate the lack of synchronization in said AM transmitters.

15. The invention defined in claim 14 wherein said reference station measures the frequency and wavelength variations in said AM signals and conveys same to said mobile station by said cellular telephone.

16. The invention defined in claim 14 including means for detecting outages or blockages in said GPS signal and including said means for receiving.

17. The invention defined in claim 14 including means for storing the frequency and geographic positions of said plurality of AM transmitters and means for selecting therefrom said predetermined number.

18. The invention defined in any one of claims 1-17 including a user service center accessible via said cellular phone to provide user services selected from one or more of the following: emergency roadside assistance, personal emergency response, vehicle tracking assistance, traveler information assistance, traffic management assistance, and fleet management.

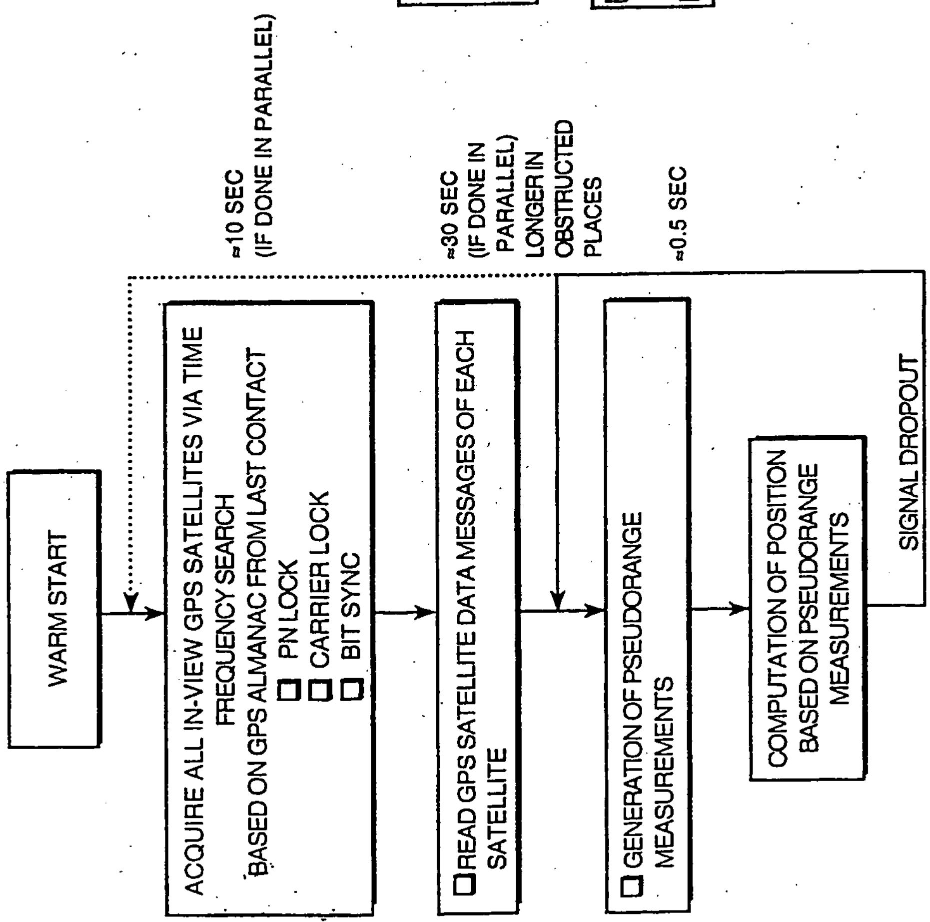


FIG. 1 (PRIOR ART)

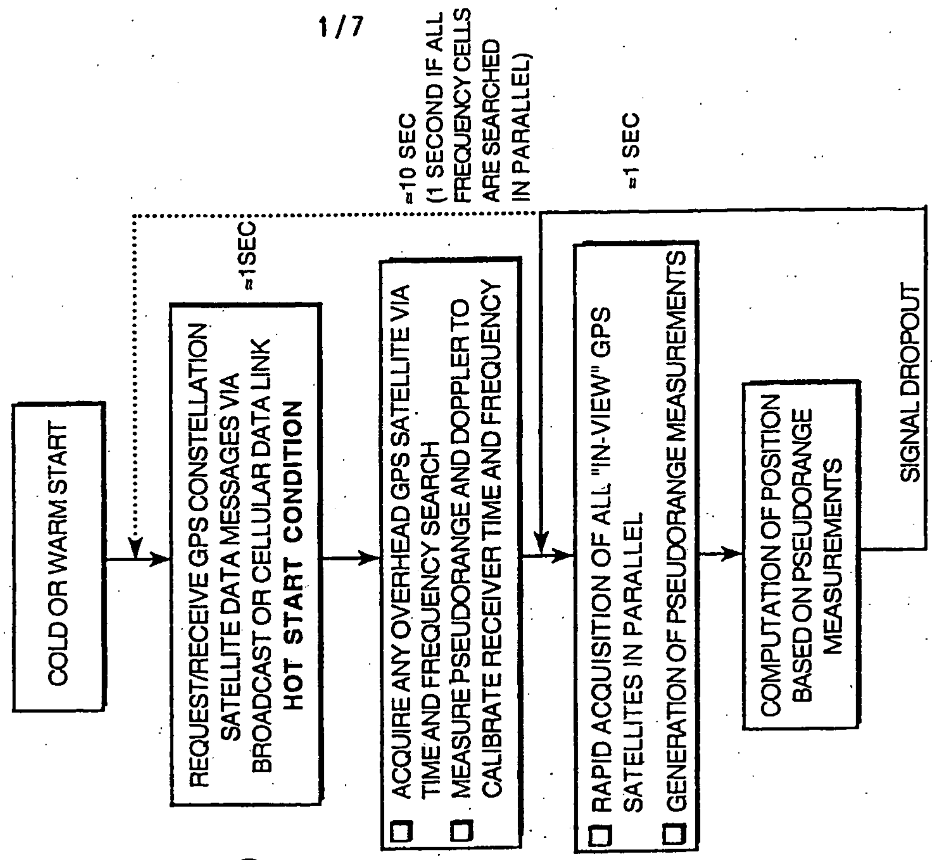


FIG. 2

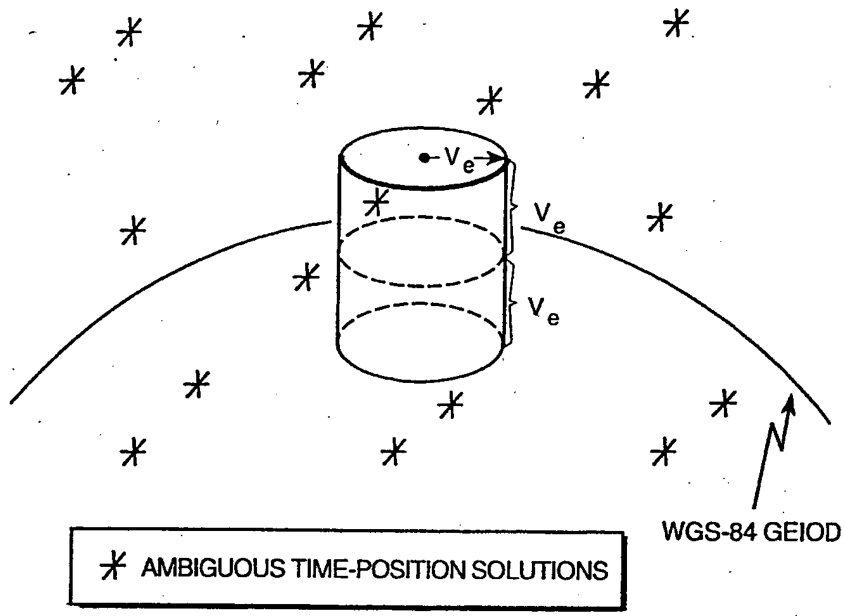

V_e
V_e
V_e
WGS-84 GEIOD
AMBIGUOUS TIME-POSITION SOLUTIONS

FIG. 3

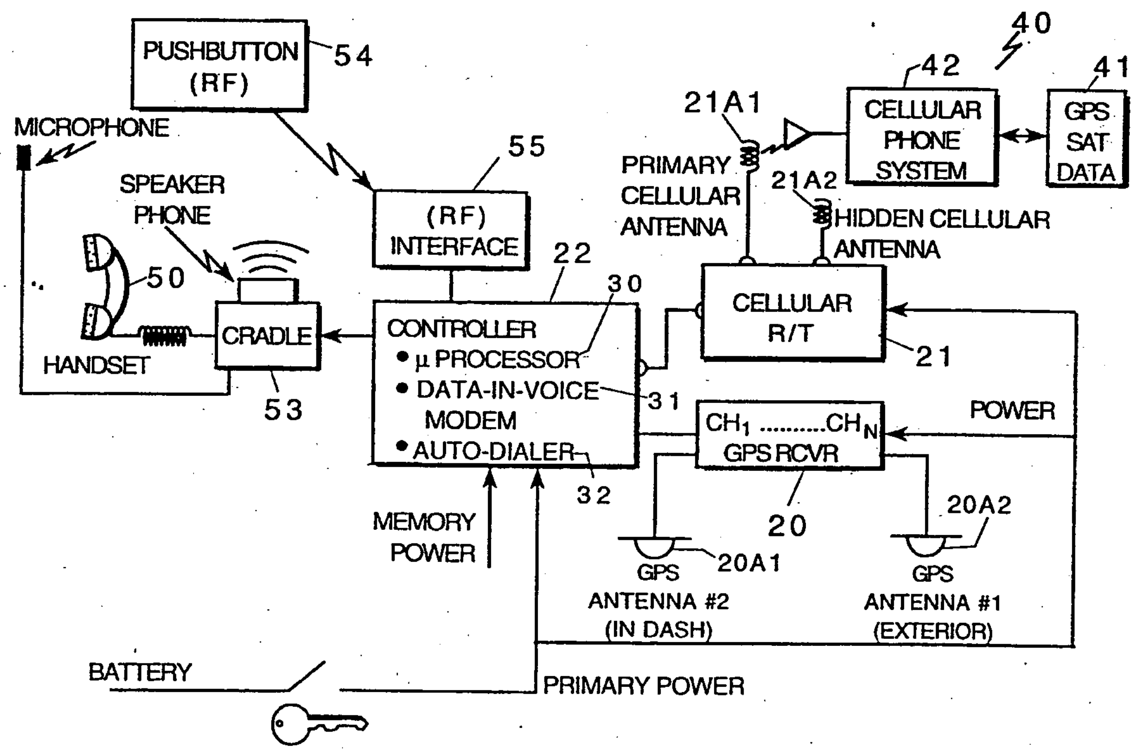

PUSHBUTTON (RF)
54
MICROPHONE
55
(RF) INTERFACE
SPEAKER PHONE
50
HANDSET
CRADLE
53
22
30
CONTROLLER
• µ PROCESSOR
• DATA-IN-VOICE MODEM
• AUTO-DIALER
31
32
MEMORY POWER
BATTERY
PRIMARY POWER
40
42
41
21A1
CELLULAR PHONE SYSTEM
GPS SAT DATA
PRIMARY CELLULAR ANTENNA
21A2
HIDDEN CELLULAR ANTENNA
CELLULAR R/T
21
POWER
CH1 ....CHN GPS RCVR
20
20A1
20A2
GPS ANTENNA #2 (IN DASH)
GPS ANTENNA #1 (EXTERIOR)

FIG. 5

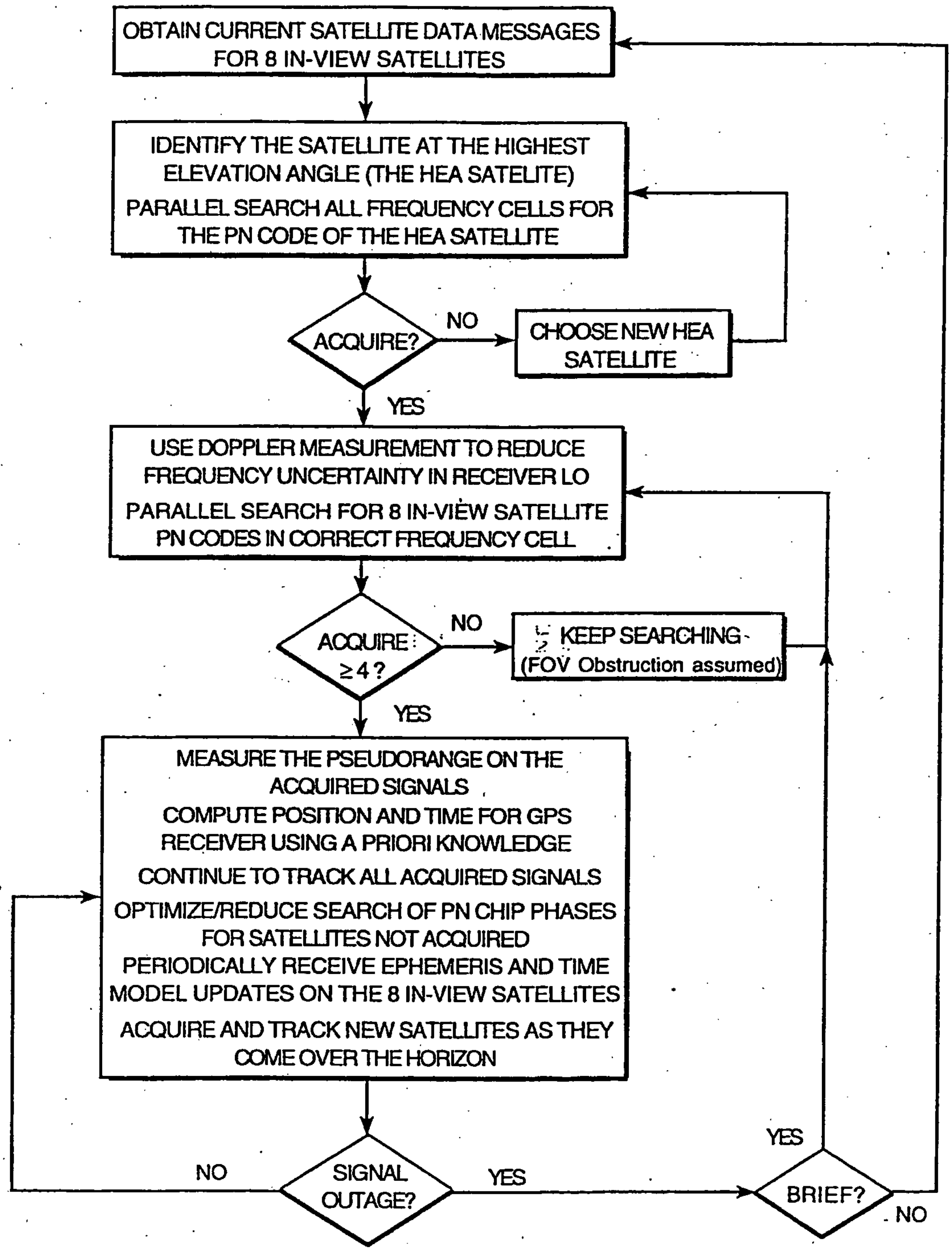

OBTAIN CURRENT SATELLITE DATA MESSAGES FOR 8 IN-VIEW SATELLITES
IDENTIFY THE SATELLITE AT THE HIGHEST ELEVATION ANGLE (THE HEA SATELITE)
PARALLEL SEARCH ALL FREQUENCY CELLS FOR THE PN CODE OF THE HEA SATELLITE
ACQUIRE?
NO
CHOOSE NEW HEA SATELLITE
YES
USE DOPPLER MEASUREMENT TO REDUCE FREQUENCY UNCERTAINTY IN RECEIVER LO
PARALLEL SEARCH FOR 8 IN-VIEW SATELLITE PN CODES IN CORRECT FREQUENCY CELL
ACQUIRE ≥4?
NO
KEEP SEARCHING (FOV Obstruction assumed)
YES
MEASURE THE PSEUDORANGE ON THE ACQUIRED SIGNALS
COMPUTE POSITION AND TIME FOR GPS RECEIVER USING A PRIORI KNOWLEDGE
CONTINUE TO TRACK ALL ACQUIRED SIGNALS
OPTIMIZE/REDUCE SEARCH OF PN CHIP PHASES FOR SATELLITES NOT ACQUIRED
PERIODICALLY RECEIVE EPHEMERIS AND TIME MODEL UPDATES ON THE 8 IN-VIEW SATELLITES
ACQUIRE AND TRACK NEW SATELLITES AS THEY COME OVER THE HORIZON
NO
SIGNAL OUTAGE?
YES
YES
BRIEF?
NO

FIG. 4

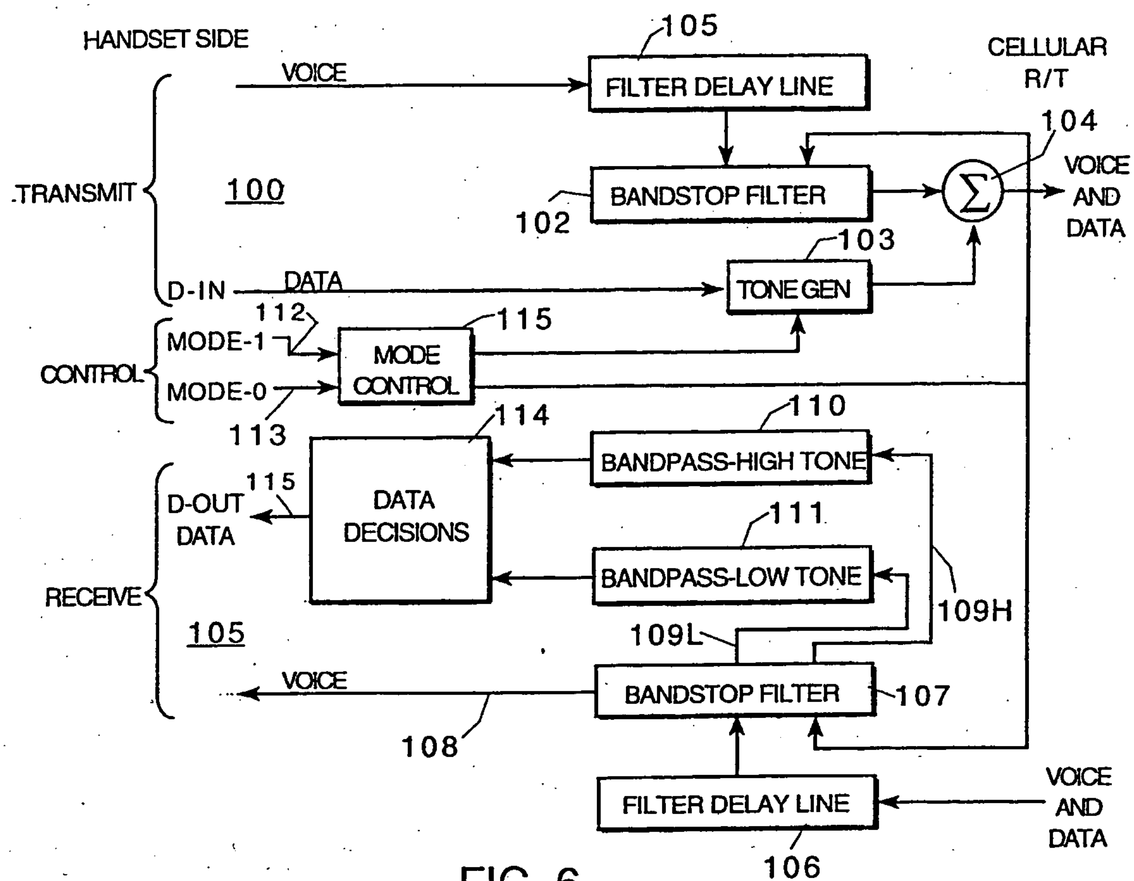


FIG. 6

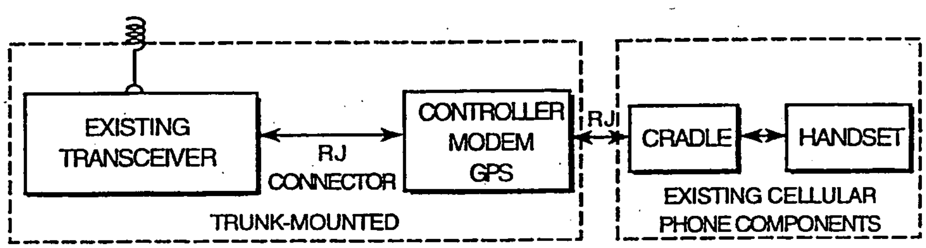


FIG. 7a

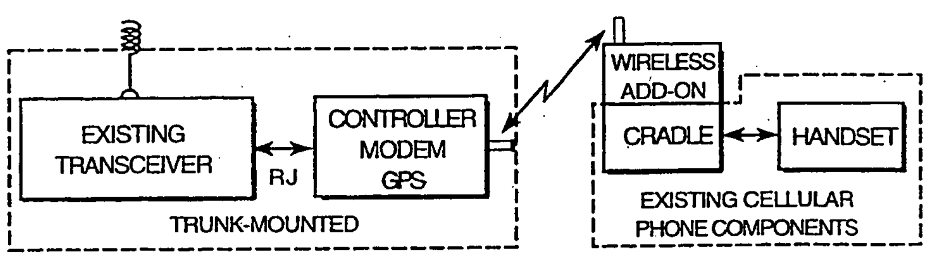
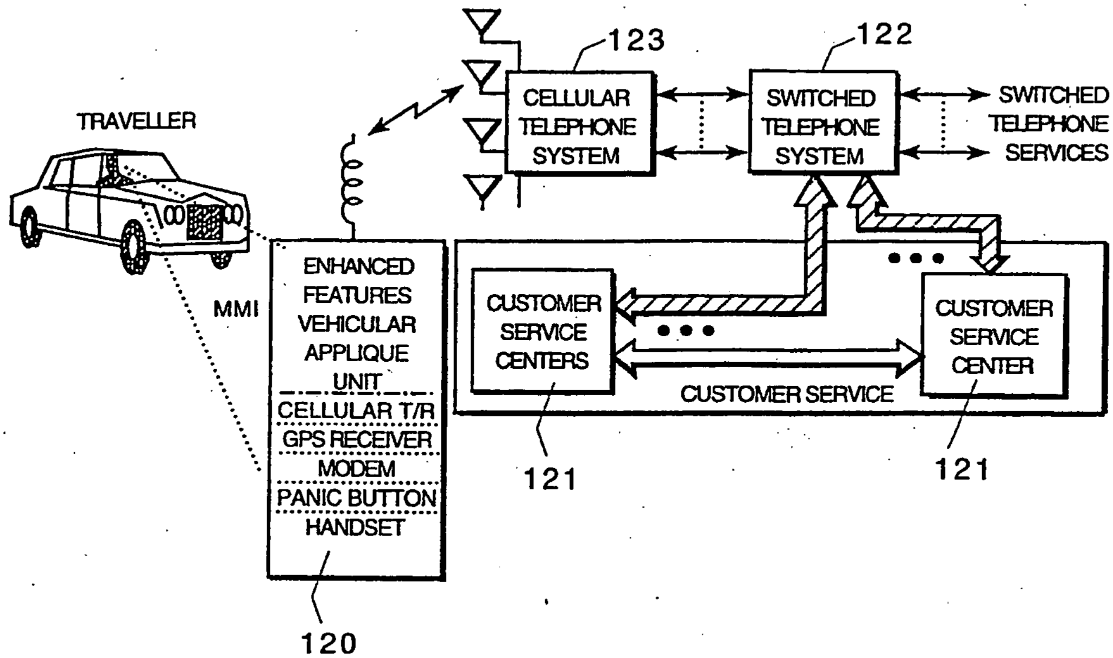
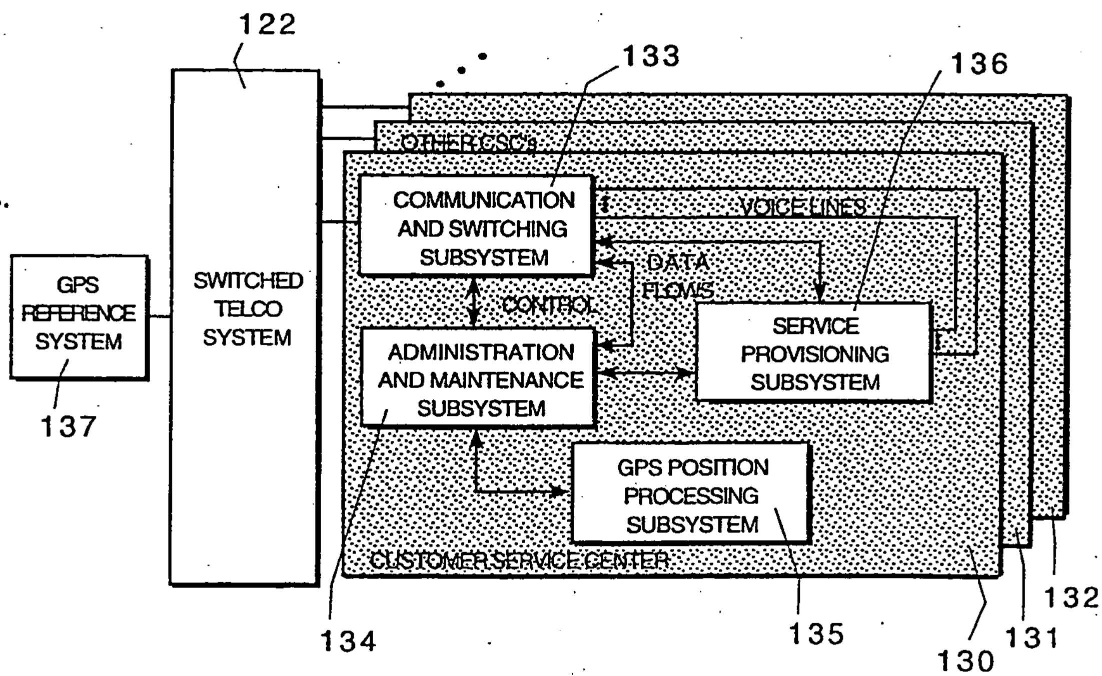


FIG. 7b



TRAVELLER
MMI
123
CELLULAR TELEPHONE SYSTEM
122
SWITCHED TELEPHONE SYSTEM
SWITCHED TELEPHONE SERVICES
ENHANCED FEATURES VEHICULAR APPLIQUE UNIT
CELLULAR T/R
GPS RECEIVER
MODEM
PANIC BUTTON
HANDSET
120
CUSTOMER SERVICE CENTERS
CUSTOMER SERVICE CENTER
CUSTOMER SERVICE
121
121

FIG. 8



122
133
136
GPS REFERENCE SYSTEM
137
SWITCHED TELCO SYSTEM
OTHER CSC's
COMMUNICATION AND SWITCHING SUBSYSTEM
VOICE LINES
DATA FLOWS
CONTROL
ADMINISTRATION AND MAINTENANCE SUBSYSTEM
SERVICE PROVISIONING SUBSYSTEM
GPS POSITION PROCESSING SUBSYSTEM
CUSTOMER SERVICE CENTER
134
135
130
131
132

FIG. 9

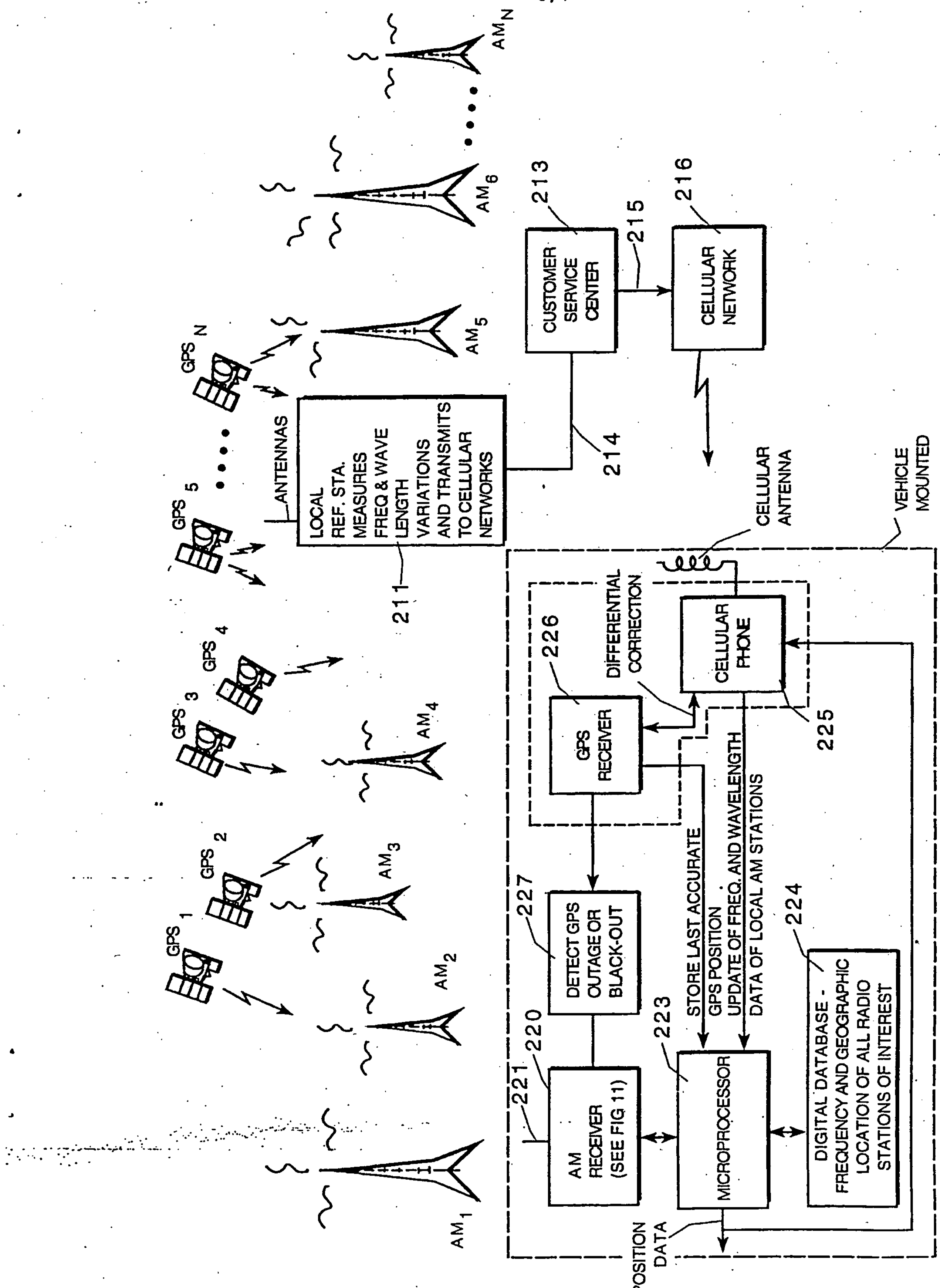
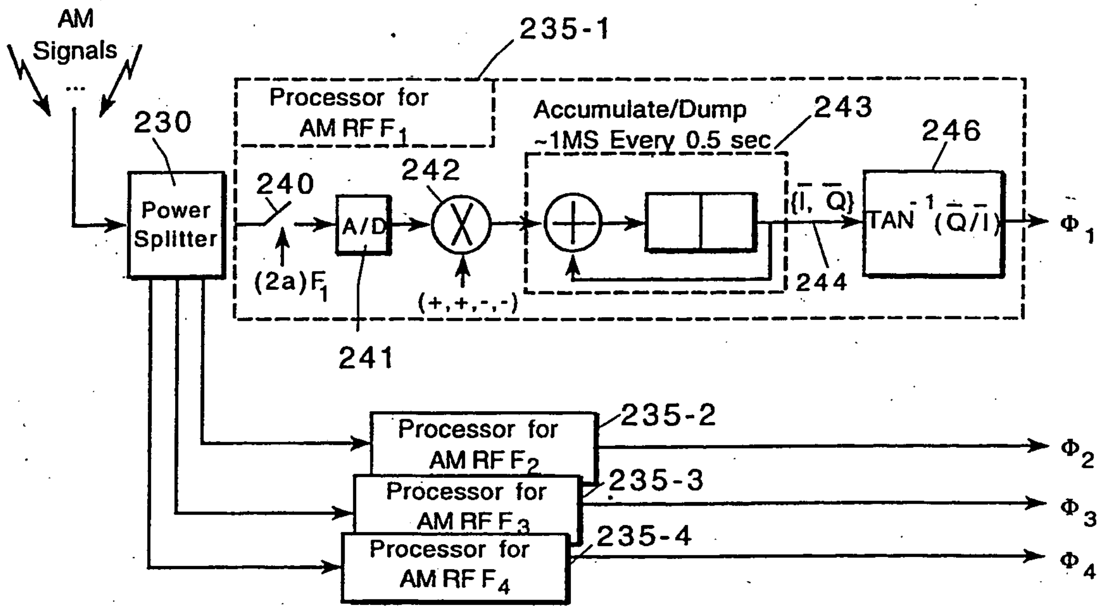

GPS 1
GPS 2
GPS 3
GPS 4
GPS 5
GPS N
AM1
AM2
AM3
AM4
AM5
AM6
AMN
ANTENNAS
LOCAL REF. STA. MEASURES FREQ & WAVE LENGTH VARIATIONS AND TRANSMITS TO CELLULAR NETWORKS
211
214
CUSTOMER SERVICE CENTER
213
215
CELLULAR NETWORK
216
CELLULAR ANTENNA
VEHICLE MOUNTED
DIFFERENTIAL CORRECTION
CELLULAR PHONE
225
226
GPS RECEIVER
227
DETECT GPS OUTAGE OR BLACK-OUT
STORE LAST ACCURATE GPS POSITION
UPDATE OF FREQ. AND WAVELENGTH DATA OF LOCAL AM STATIONS
221
220
AM RECEIVER (SEE FIG 11)
223
MICROPROCESSOR
224
DIGITAL DATABASE - FREQUENCY AND GEOGRAPHIC LOCATION OF ALL RADIO STATIONS OF INTEREST
POSITION DATA

FIG. 10



MATHEMATICAL DESCRIPTION

- a(t) Represents AM Information; w is AM Carrier Radian Frequency; (Reflects Reference Station Corrections); wt i is Odd Multiple of $\pi/2$
- I-Samples: $A[1+a(t_i)] \cos [wt_i + \Phi] \sim A[1+a(t_i)] \cos \Phi$
- Q-Samples: $A[1+a(t_i+\delta)] \sin [wt_i + \Phi] \sim A[1+a(t_i)] \sin \Phi ; a(t_i+\delta) \sim a(t_i)$ for $\delta \sim 1\mu s$
- $\bar{I} \sim A\sum_i [1+a(t_i)] \cos \Phi ; \bar{Q} \sim A \sum_i [1 + a(t_i)] \sin \Phi$

Note: Φ Varies Negligibly Over Averaging Interval (~ 1 ms)

$$\Rightarrow \boxed{\Phi = TAN^{-1} (\bar{Q}/\bar{I})}$$

FIG. 11

INTERNATIONAL SEARCH REPORT

International application No. PCT/US93/12179

A. CLASSIFICATION OF SUBJECT MATTER

IPC(5) :Please See Extra Sheet.
US CL : 364/449, 452,443; 342/457,450
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 364/449, 452,443, 460 ; 342/457,450,451,463

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Please See Extra Sheet.

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y,P	US,A, 5,223,844 (Mansell et al) 29 June 1993 see columns 2,5-10, and 14	1,5-10, 11-13, 14-18
Y,P	US,A, 5,218,618 (Sagey) 8 June 1993 See abstract; col. 1, lines 55-66; col.2, lines 5-15; col. 2,lines 32-48.	11-13
X --- A	US,A, 4,785,463 (Janc et al) 15 November 1988 see col.3, lines 56-60; columns 5,19,and 20	2,3 ------- 4
Y,P	US,A, 5,173,710 (Kelley et al) 22 December 1992 see abstract; columns 1,2; col. 4, lines 9-25; col. 5, lines 18-21;.col. 5, lines 46-68; col. 6, lines 43-68	14-18

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be part of particular relevance

"E" earlier document published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
02 MAY 1994	01 JUN 1994
Name and mailing address of the ISA/US Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231 Facsimile No. (703) 305-9564	Authorized officer B. Hardi for Tom Black Telephone No. (703) 305-9758

Form PCT/ISA/210 (second sheet)(July 1992)*

INTERNATIONAL SEARCH REPORT

International Application No.
PCT/US93/12179

A. CLASSIFICATION OF SUBJECT MATTER:
IPC (5):

H04B 7/185; G01S 5/02; H04L 27/30

B. FIELDS SEARCHED
Documentation other than minimum documentation that are included in the fields searched:

APS search: GPS and cellular telephone
GPS and AM
GPS and oscillator and calibrat?